An Investigation of Seismicity For The Aegean and Mediterranean Regions

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Abstract — In order to investigate the seismicity of Aegean and Mediterranean regions limited with the coordinates of 35°-39°N, 26°-38°E, Gutenberg-Richter magnitude-frequency relation, seismic risk and recurrence period have been computed. The data belonging to both the historical period before 1900 ($I_0 \geq 5.0$ corresponding to $M_S \geq 4.4$) and the instrumental period until 2007 ($M_S \geq 4.0$) has been used in the analysis. The study area has been divided into 15 sub-regions due to certain seismotectonic characteristics, plate tectonic models and geology of the region. All the computations have been performed for these sub-regions, separately. According to the results, a and b values in the computed magnitude-frequency relations are in the intervals 3.10±0.24-5.29±0.52 and 0.39±0.03-0.73±0.08, respectively. The highest b values have been determined for sub-regions 7 (Gökova Gulf-Muğla-Gölhisar) and 1 (Izmir- Sakız Island). The lowest b values have also been determined for sub-regions 15 and 8 (Antakya and Bodrum-İstanköy). Finally, seismic risk and recurrence period computations from a and b values have shown as expected that sub-regions 15 and 8 which have the lowest b values and the highest risks and the shortest-recurrence periods.

Keywords — Aegean and Mediterranean Regions, Poisson model, Recurrence period, Seismicity.

I. INTRODUCTION

One of the most seismically active regions in the world is the Alpine-Himalayan Belt which extends from the Azores to Indonesia Anatolia locates in the most active section of this belt in the eastern Mediterranean and involves several important tectonic structures such as North Anatolian Fault Zone (NAFZ), East Anatolian Fault Zone (EAFZ), North-East Anatolian Fault Zone (NEAFZ) and Bitlis Thrust Belt (BTB) shown in Fig. 1. Therefore Anatolia has been exposed to strong earthquakes along the history. Focal mechanisms of earthquakes in western Anatolia indicate that intra-plate deformations arising from vertical movements are occurring inside of the Aegean-Anatolian block. Most of the fault-plane solutions in western Anatolia represent normal faulting, indicative of crustal extension. Tensional axes for these solutions are nearly horizontal and perpendicular to the general east-west trend of graben structure. The Arabian plate moves northward, and forces the smaller Anatolian plate westward between the North and the East Anatolian Fault Zones as from Karliova triple junction. [1], [2] showed that this motion is transferred into the Aegean in a southwesterly direction, resulting in the northern Aegean being dominated by dextral strike-slip faulting of northeasterly strike. This faulting type has been seen in the recent strong earthquakes, and confirmed by neotectonic observations.

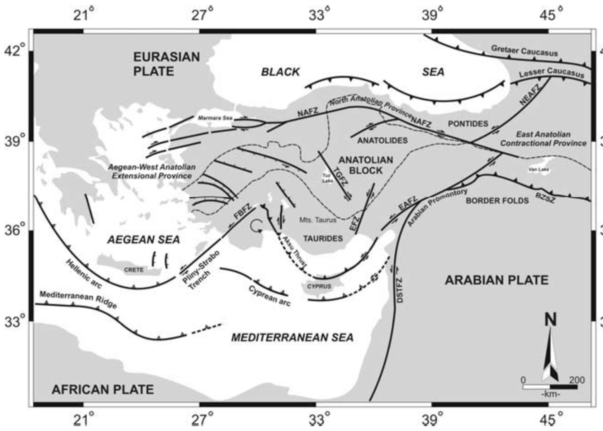

Fig 1. Neotectonics of Turkey and surrounding area [14].

The subject of this study is to estimate the probability of earthquake occurrences and recurrence periods by using Poisson model from historical and instrumental data for selected characteristic sub-regions in Aegean and Mediterranean regions.

II. DATA

Both historical (since BC-222, $I_0 \geq 5.0$ corresponding to $M_S \geq 4.4$) and instrumental period (until 2007, $M_S \geq 4.0$), data obtained from the catalogues and bulletins of international data centers have been used in this study. Homogeneity of the data is very important in the analysis. In order to ensure homogeneity, all of the magnitudes have been taken as surface wave magnitude (M_S). These magnitudes have been determined by seismologists who compiled the catalogues either from recordings of long-period seismometers, or through the use of experimental scaling relations. Possible discrepancies between the magnitudes computed by different authors for the same earthquake are small, and do not affect the results much in any case.

The experimental scaling relation (1) between surface (M_S) and body wave magnitudes (m_b) has been estimated by using 190 earthquakes of $M_S \geq 3.0$ and $m_b \geq 3.5$ taken from the dataset in the instrumental period. Likewise, the correlation between intensity and magnitude has been determined (2) from the data of 115 earthquakes ($M_S \geq 4.4$) occurred in the instrumental period (Fig. 2). Computed M_S-I_o and M_S-m_b relations are consistent with those of [3] and [4], respectively.

$$M_S = 1.19 m_b - 1.36 \quad (1)$$

$$M_S = 0.47 I_o + 2.05 \quad (2)$$

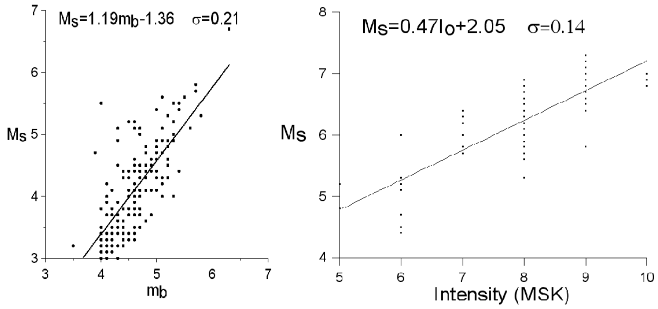

Fig. 2 Correlations of M_s-m_b and M_s-I_o used in this study.

An important criterion for the analysis is completeness of the data. Namely, the data must include all of the earthquakes that occurred in a certain seismogenic region during a specific time-period with magnitudes larger than a specific minimum (cut-off) magnitude. According to this statement, the smallest magnitude from which earthquakes were reliably reported in the catalogues (historical and instrumental period) used has been chosen as a minimum magnitude (M_{min} = 4.0 in our case for all sub-regions) in each region. Maximum magnitude value (M_{max}) is magnitude of the biggest earthquake for each sub-region.
Another important criteria is to select the main shocks from dataset. Namely, the dataset has to be cleared from after- and for-shocks to be able to use it in Gutenberg-Richter relationship. Thus, after- and for-shocks has been rejected from dataset.

III. DEFINITION OF THE METHOD

Since magnitude-frequency relations are formed as the basis of the earthquake occurrence, it is used for the criterion of earthquake activity as times ago. In the investigation of earthquake occurrence frequencies, it seems that they exhibit usually a linear relation. An equation to represent the relation between the magnitude and earthquake occurrence frequencies has been suggested by [5]. Equation (3) is:

$$LogN(M) = a - bM \tag{3}$$

where N(M) (cumulative frequency), is the number of earthquakes equal or larger than M magnitude. Gutenberg-Richter relation does not become linear for all magnitudes. Therefore, the magnitude interval (M_1, M_2) in which the logN(M) is linear must be known. So that, the relation is undetermined for the large earthquakes since they are a few number. On the other hand, it must be sure that earthquake array is complete for the small earthquakes.

Parameters (a) and (b) in the magnitude-frequency relation are constants. Parameter (a) depends on the observation period, the order of the region interested and the seismic activity, and defines a mean annual seismic activity index. Parameter (b) is related to the physics of the earthquakes and gives slope of the linear relation. According to the analysis of worldwide data, it has been noted that b values considerably change as depending on the geological age of the seismotectonic belt [4]. In general, low b-values are related to high stress-drop, high b-values are related to high heterogeneity of material and crack [7]—[9] dataset, a and b-values are commonly computed by using the linear least square approximation in (4);

$$\sum_{i=1}^{n} LogN_i = an - b\sum_{i=1}^{n} M_i,\quad \sum_{i=1}^{n} M_i.LogN_i = a\sum_{i=1}^{n} M_i - b\sum_{i=1}^{n} M_i^2 \tag{4}$$

$$a' = a - Log(b\ln 10),\quad a'_1 = a' - LogT_1,\quad n(M) = 10^{a'_1 - bM},\quad R(M) = 1 - e^{-n(M)T},\quad Q = \frac{1}{n(M)} \tag{5}$$

where n is the number of group. The annual mean number n of earthquakes ($M \geq M_1$) with specific magnitude equal and larger than M_1 value in a specific time can be estimated by using these relations. In any regions, occurrence risk in T years of an earthquake with any magnitude M for observation interval of T_1 year is calculated by R(M) in (5) and recurrence period of an earthquake is estimated by Q in (5) [10].

IV. ANALYSIS FOR AEGEAN AND MEDITERRANEAN REGIONS

Definition of seismogenic sub-regions

A seismogenic sub-region must include seismically homogenous fault segment where every point is assumed as having the same probability for a future earthquake. Sub-regions are mainly defined by two fundamental characteristics. These are a seismic profile and the tectonic regime of the region. Sub-regions should be defined as characteristic seismic areas which are as homogenous as possible.

Marking the boundaries between sub-regions is quite difficult in the seismically complex regions like Anatolia. The boundary between sub-regions of different seismic potential should be located close to the highest concentration around the hard core of the more active ones. In these cases, all the possible characteristics such as the distribution of epicenters, the type of faulting, geomorphological conditions, seismicity and the largest event should be taken account. Under the points of this view, study area has been divided into 15 sub-regions (Fig. 3).

Computation of seismic risk and recurrence period

In this study, the linear least square method (4) has been applied to obtain a and b parameters in (3) for each sub-region shown in Fig. 2 using the earthquakes of $M_S \geq 4.0$ occurred from BC-496 to 2007. Distribution of the earthquakes with the magnitude increment of 0.5 and cumulative frequency values for each sub-region have been given in Table 1. Fig. 4 shows the magnitude-frequency relations. Seismic risk and recurrence period values have been estimated by using a and b parameters given in Table 2. In the computations, magnitudes of $M_S \geq 5.0$ and increment interval of 0.5 were chosen, and the relations in (3) for seismic risk and recurrence period are used.

Observational time interval (T_1 year) has been determined by the completeness condition of each sub-region. Maximum magnitude value (M_{max}) has been selected as magnitude of the biggest earthquake for each sub-region.

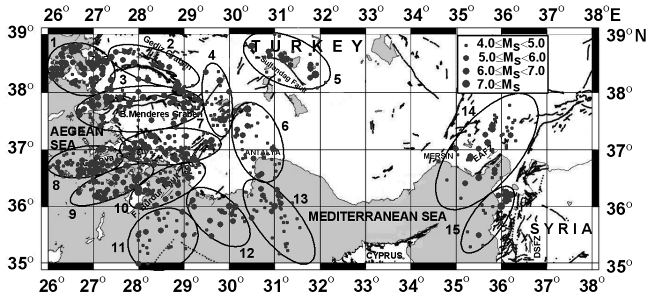

Fig. 3 Epicentral map and selected 15 sub-regions of Aegean and Mediterranean regions.

Table 1. Cumulative frequencies (N_i) with the magnitude increment of 0.5 for the earthquakes occurred in each sub-region.

Magnitudes (M_S)	Cumulative frequencies (N_i) for each sub-region 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4.0-4.4	142	27	100	65	31	46	106	84	66	69	39	24	35	42	21
4.5-4.9	113	14	65	29	20	19	58	43	30	33	22	12	15	26	10
5.0-5.4	88	11	46	7	15	8	35	31	20	17	12	10	8	11	6
5.5-5.9	39	4	18	3	5	2	4	6	11	9	3	3	4	9	5
6.0-6.4	24	2	11	1	4	1	3	4	6	4	0	2	1	3	3
6.5-6.9	10	2	6	0	2	1	1	3	3	4	0	1	0	0	3
7.0.7.4	0	0	1	0	1	1	0	2	0	1	0	0	0	0	3
7.5-7.9	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1

Table 2. a and b-values with a standard errors estimated by the linear least square method for each sub-region.

Sub-Regions	Completeness date (d/m/yr)	Earthquake number	a	b
1 İzmir-Sakız Island	01.01.1639	142	5.29±0.52	0.66±0.09
2 Manisa-Salihli	23.02.1652	27	3.19±0.24	0.45±0.04
3 Sisam Is.-Aydın-Denizli	07.06.1751	100	4.74±0.32	0.63±0.05
4 Dinar-Çivril	04.10.1914	65	3.84±0.57	0.63±0.09
5 Bolvadin-Afyonkarahisar	16.10.1862	31	3.48±0.19	0.48±0.03
6 Antalya Gulf	03.10.1914	46	3.50±0.55	0.55±0.09
7 Gökova Gulf-Muğla-Gölhisar	24.08.1920	106	4.73±0.51	0.73±0.08
8 Bodrum-İstanköy	27.08.1886	84	3.30±0.37	0.43±0.06
9 Bozburun-Sombeki Island	18.10.1844	66	4.10±0.17	0.54±0.02
10 Fethiye-Rodos Island	28.02.1852	69	4.06±0.21	0.55±0.03
11 west of the Cyprus Arc	04.04.1925	39	3.62±0.51	0.55±0.08
12 Kaş-Finike Gulf	30.04.1912	24	3.11±0.31	0.46±0.05
13 Kumluca- Kırlangıç offshore	05.06.1927	35	3.36±0.44	0.53±0.07
14 İskenderun Gulf-Andırın	17.02.1908	42	3.81±0.31	0.54±0.05
15 Antakya	13.08.1822	21	3.10±0.24	0.39±0.03

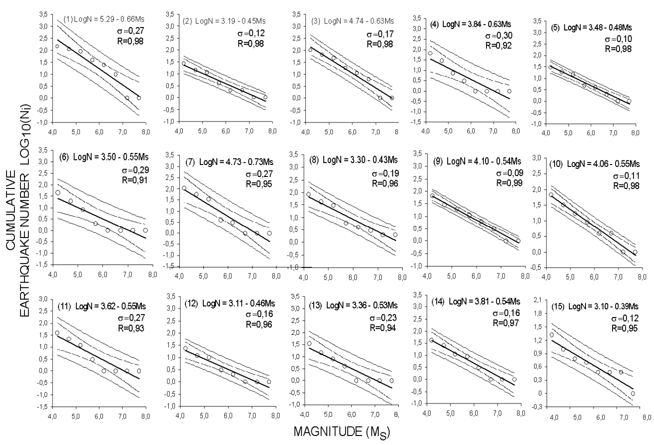

Fig 4. Magnitude-frequency relations computed by the linear least square method. Thick line shows the estimated relation. Broken and thin lines show confidence interval band of %95 and prediction interval band. σ and R are standard deviation and correlation coefficient, respectively.

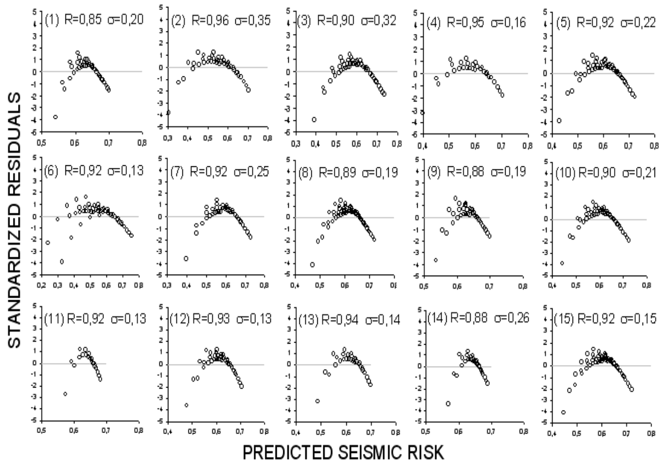

Fig 5. The standardized residuals versus the predicted seismic risk for each sub-region. σ and R are standard deviation and correlation coefficient, respectively.

Computations have been done for decades in the next 100 years in each sub-region. The results for sub-regions with lowest and highest b-values have only been shown in Table 3 for projection. The standardized residuals of the predicted seismic risk values have been determined. The standardized residuals show in Fig. 5.

Table 3. Seismic risk and recurrence period values estimated by using a and b-values for the earthquakes of $5.0 \leq M_S \leq M_{max}$ with the magnitude increment of 0.5 in observation interval (T_1 year) of each sub-region. Maximum magnitude value (M_{max}) is magnitude of the biggest earthquake for each sub-region.

Sub-regions	Mag. (M_S)	Seismic risk R(M)% Period (year) 10	20	30	40	50	60	70	80	90	100	Recur. period Q (year)
1 (T_1=369 yr) M_{max}=6.8	5.0	82.5	96.9	99.5	99.9	100	100	100	100	100	100	5
	5.5	55.7	80.4	91.3	96.2	98.3	99.2	99.7	99.9	99.9	100	10
	6.0	31.7	53.4	68.1	78.2	85.1	89.8	93.1	95.3	96.8	97.8	20
	6.5	16.3	30	41.4	51	59	65.7	71.3	76	79.9	83.2	40
2 (T_1=356 yr) M_{max}=6.9	5.0	21.0	37.6	50.8	61.1	69.3	75.7	80.8	84.9	88.1	90.6	35
	5.5	13.1	24.5	34.4	43.0	50.5	57.0	62.6	67.5	71.8	75.5	85
	6.0	8.0	15.4	22.2	28.5	34.2	39.5	44.4	48.8	53.0	56.7	175
	6.5	4.9	9.5	13.9	18.1	22.1	25.9	29.5	32.9	36.2	39.3	180
3 (T_1=257 yr) M_{max}=7.2	5.0	64.8	87.6	95.6	98.5	99.5	99.8	99.9	100	100	100	6
	5.5	39.7	63.6	78.0	86.7	92.0	95.2	97.1	98.2	98.9	99.4	17
	6.0	21.7	38.7	52.0	62.4	70.6	77.0	82.0	85.9	88.9	91.3	30
	6.5	11.2	21.1	29.9	37.7	44.7	50.9	56.4	61.2	65.6	69.4	45
	7.0	5.6	10.8	15.8	20.5	24.9	29.1	33.1	36.8	40.3	43.6	246
4 (T_1=94 yr) M_{max}=6.0	5.0	30.2	51.2	66.0	76.2	83.4	88.4	91.9	94.3	96.1	97.2	10
	5.5	16.0	29.4	40.7	50.1	58.1	64.8	70.4	75.1	79.1	82.4	30
	6.0	8.1	15.5	22.3	28.6	34.4	39.7	44.5	49.0	53.1	56.9	90
5 (T_1=146 yr) M_{max}=7.0	5.0	52.5	77.5	89.3	94.9	97.6	98.9	99.5	99.7	99.9	99.9	10
	5.5	34.9	57.6	72.4	82	88.3	92.4	95	96.8	97.9	98.6	25
	6.0	21.9	38.9	52.3	62.7	70.9	77.2	82.2	86.1	89.1	91.5	35
	6.5	13.2	24.7	34.7	43.3	50.8	57.3	63	67.9	72.1	75.8	70
	7.0	7.8	15.1	21.7	27.9	33.5	38.7	43.6	48	52.1	55.8	142
6 (T_1=94 yr) M_{max}=7.0	5.0	37.6	37.6	75.8	84.9	90.6	94.1	96.3	97.7	98.6	99.1	11
	5.5	22.2	22.2	52.9	63.3	71.5	77.8	82.7	86.6	89.5	91.9	40
	6.0	12.5	12.5	32.9	41.3	48.6	55.0	60.6	65.5	69.8	73.6	64
	6.5	6.8	6.8	19.1	24.6	29.8	34.6	39.0	43.2	47.1	50.7	85
	7.0	3.7	3.7	10.6	13.9	17.1	20.2	23.1	25.9	28.7	31.3	104
7 (T_1=88 yr) M_{max}=6.5	5.0	55.6	80.3	91.3	96.1	98.3	99.2	99.7	99.9	99.9	100	3
	5.5	29.6	50.4	65.1	75.4	82.7	87.8	91.4	94.0	95.7	97.0	21
	6.0	14.0	26.1	36.5	45.4	53.1	59.7	65.3	70.2	74.4	78.0	25
	6.5	6.3	12.2	17.8	23.0	27.9	32.4	36.7	40.7	44.4	48.0	79
8 (T_1=122 yr) M_{max}=7.6	5.0	68.9	90.4	97.0	99.1	99.7	99.9	100	100	100	100	4
	5.5	51.0	76.0	88.2	94.2	97.2	98.6	99.3	99.7	99.8	99.9	20
	6.0	35.2	58.1	72.8	82.4	88.6	92.6	95.2	96.9	98.0	98.7	30
	6.5	23.3	41.1	54.8	65.3	73.4	79.6	84.3	88.0	90.8	92.9	38
	7.0	14.9	27.6	38.4	47.6	55.4	62.0	67.7	72.5	76.6	80.1	60
	7.5	9.4	17.9	25.6	32.5	38.9	44.6	49.8	54.5	58.8	62.6	85
9 (T_1=164 yr) M_{max}=6.7	5.0	70.8	91.5	97.5	99.3	99.8	99.9	100	100	100	100	8
	5.5	48.4	73.4	86.3	92.9	96.3	98.1	99.0	99.5	99.7	99.9	15
	6.0	29.9	50.9	65.6	75.9	83.1	88.1	91.7	94.2	95.9	96.1	28
	6.5	17.4	31.7	43.6	53.4	61.5	68.2	73.7	78.3	82.0	85.2	52
10 (T1=156 yr) Mmax=7.2	5.0	64.4	87.3	95.5	98.4	99.4	99.8	99.9	100	100	100	9
	5.5	42.2	66.6	80.7	88.9	93.6	96.3	97.9	98.8	99.3	99.6	18
	6.0	25.3	44.2	58.3	68.8	76.7	82.6	87	90.3	92.7	94.6	34
	6.5	14.3	26.6	37.1	46.1	53.8	60.5	66.1	71	75.1	78.7	45
	7.0	7.9	15.1	21.8	28	33.7	38.9	43.7	48.1	52.2	56.0	120

11 (T_1=83 yr)	5.0	50.6	75.6	87.9	94.0	97.1	98.5	99.3	99.6	99.8	99.9	8
M_{max}=5.7	5.5	31.2	52.7	67.5	77.6	84.6	89.4	92.7	95.0	96.6	97.6	25
12 (T_1=96 yr)	5.0	47.0	71.9	85.1	92.1	95.8	97.8	98.8	99.4	99.7	99.8	10
M_{max}=6.8	5.5	31.2	52.7	67.4	77.6	84.6	89.4	92.7	95.0	96.5	97.6	27
	6.0	19.8	35.6	48.3	58.5	66.7	73.3	78.6	82.8	86.2	88.9	45
	6.5	12.2	22.8	32.2	40.5	47.7	54.1	59.6	64.6	68.9	72.6	80
13 (T_1=81 yr)	5.0	40.5	64.6	78.9	87.4	92.5	95.6	97.4	98.4	99.1	99.4	10
M_{max}=6.2	5.5	24.6	43.1	57.1	67.6	75.6	81.6	86.1	89.5	92.1	94.0	25
	6.0	14.2	26.4	36.8	45.8	53.5	60.1	65.8	70.6	74.8	78.4	65
14 (T_1=100 yr)	5.0	64.5	87.4	95.5	98.4	99.4	99.8	99.9	100	100	100	9
M_{max}=6.3	5.5	42.7	67.1	81.2	89.2	93.8	96.5	98.0	98.8	99.3	99.6	15
	6.0	25.8	45.0	59.2	69.7	77.6	83.4	87.7	90.8	93.2	95.0	32
15 (T_1=186 yr)	5.0	57.1	81.6	92.1	96.6	98.5	99.4	99.7	99.9	100	100	30
M_{max}=7.5	5.5	41.7	66.0	80.2	88.5	93.3	96.1	97.7	98.7	99.2	99.5	35
	6.0	29.1	49.8	64.4	74.8	82.1	87.3	91.0	93.6	95.5	96.8	55
	6.5	19.7	35.6	48.3	58.5	66.7	73.3	78.5	82.8	86.2	88.9	60
	7.0	13.1	24.5	34.4	43.0	50.4	56.9	62.6	67.5	71.7	75.4	62
	7.5	8.6	16.4	23.6	30.1	36.1	41.6	46.6	51.2	55.3	59.2	180

V. CONCLUSIONS

In this study, seismicity of Aegean and Mediterranean regions has been investigated by means of computations of the magnitude-frequency relation, seismic risk and recurrence period, and the results tried to be interpreted and related with the active tectonic of region. The map in Fig. 3 showing the main faults and epicenter distribution demonstrate quite high seismic activity in the region. At the result of these observations, the study area has been separated to 15 sub-regions (Fig. 3). Magnitude-frequency relations have been determined by the data sets ($M_S \geq 4.0$) in different observation intervals for each sub-region. Then seismic risk and recurrence periods for the time periods of decades in the next 100 years and magnitude interval of $5.0 \leq M_S \leq 7.5$ have been estimated from a and b values computed to determine the magnitude-frequency relations.

In twos of the highest and lowest b-values were determined as 0.73±0.08, 0.66±0.09 for sub-regions 7, 1, and as 0.39±0.03, 0.43±0.06 for sub-regions 15, 8, respectively. As it well known, the high b value implies that the high seismic activity had rolled in that region. According to the seismic risk estimations, the highest earthquake occurrence probability of $M_S \geq 7.0$ in the next 100 years is %80.1 (σ=0.19, R=0.89) for sub-region 8 and %75.4 (σ=0.15, R=0.92) for sub-region 15. Recurrence times for the earthquakes with the same magnitude have been found as 60 and 62 years in these sub-regions. The highest occurrence probability and recurrence time of an earthquake with $M_S \geq 7.5$ in the next 100 years have been found as %62.6 (σ=0.19, R=0.89) and 85 years for sub-region 8, respectively. [11], [12] had applied the regional time- and magnitude-predictable model at the same sub-regions of western Anatolia and eastern Anatolia [13] by using earthquakes with the magnitude $M_S \geq 5.5$ to compute the occurrence probabilities and the recurrence intervals of large earthquakes. The conclusions of present study agree with the results of the regional time- and magnitude-predictable model.

In conclusion, the large earthquakes have occurred in western Anatolia like its other regions and will occur in the future. For this reason, seismicity studies should be continued for minimizing the losses of life and property caused by earthquakes. Therefore, the tectonics features and active faults and activity of the region should be defined carefully and followed continuously.

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